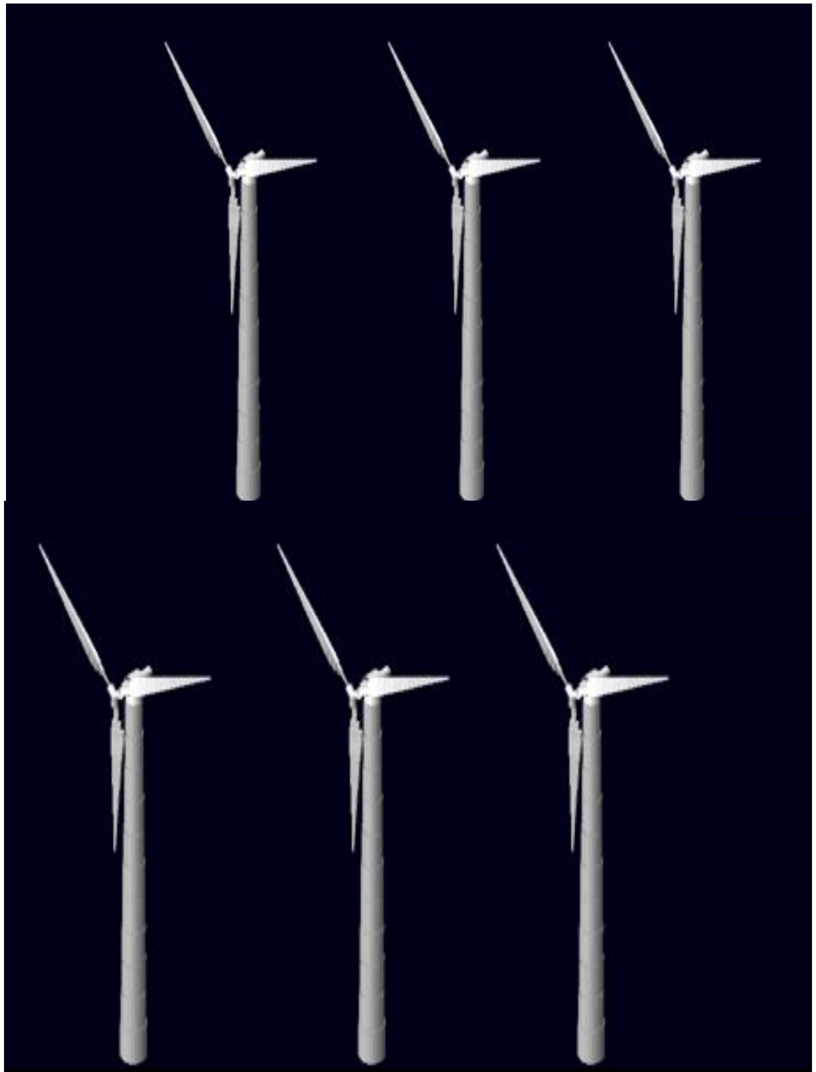
A Comprehensive Wind Energy Program

Department of Energy

Indiana Wind Working Group
Indianapolis, IN
December 3, 2010

Comprehensive Program



Wind Energy Systems

Research

Micro-reconfigurable wind farm with cooperative control

Urban wind farm rotor design and placement

Noise generation/propagation

New sensors for condition monitoring

Education / Training

Certificate program

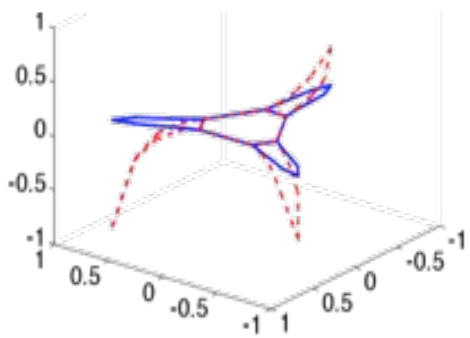
New hands-on laboratory course in wind energy

Internships (NREL, etc.)

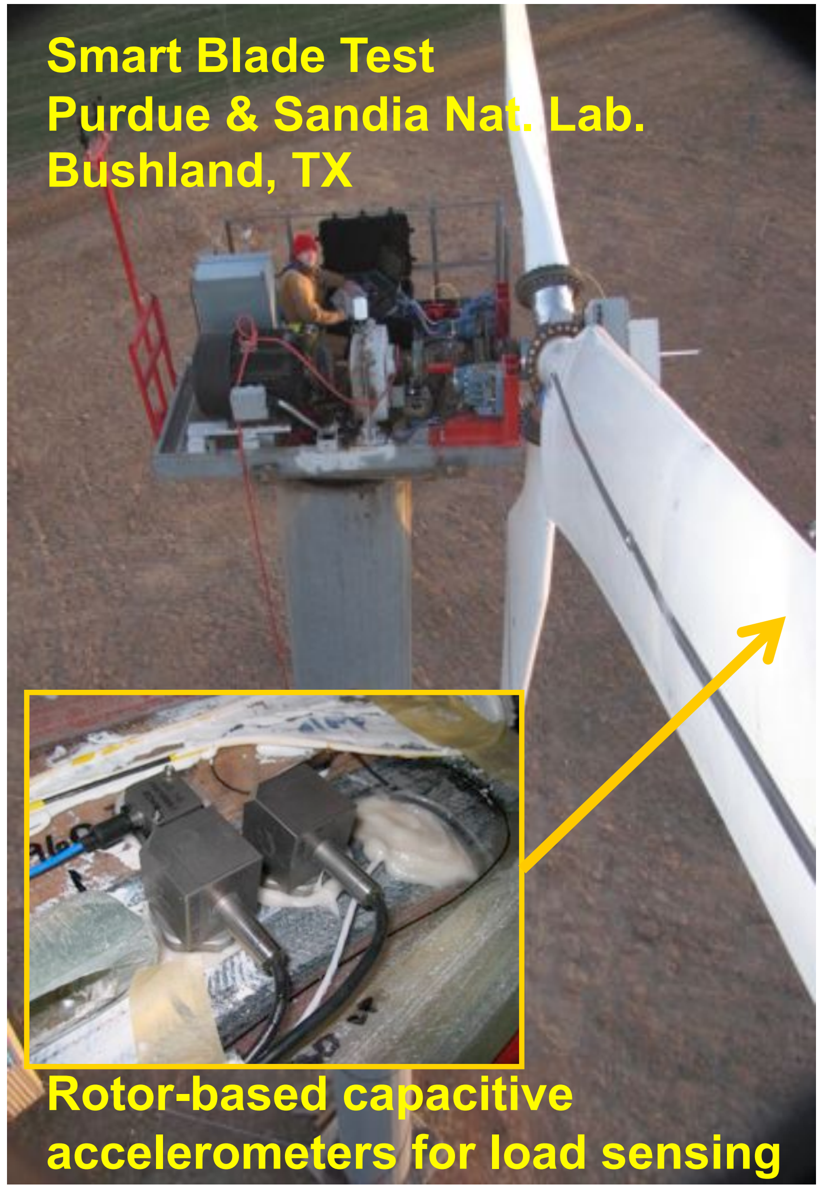
Research Vision

Smart Wind Turbines & Farms

that can sense, predict, and control their own performance & reliability



Shape loads on the rotor for energy and reliability



Simulation Based Models

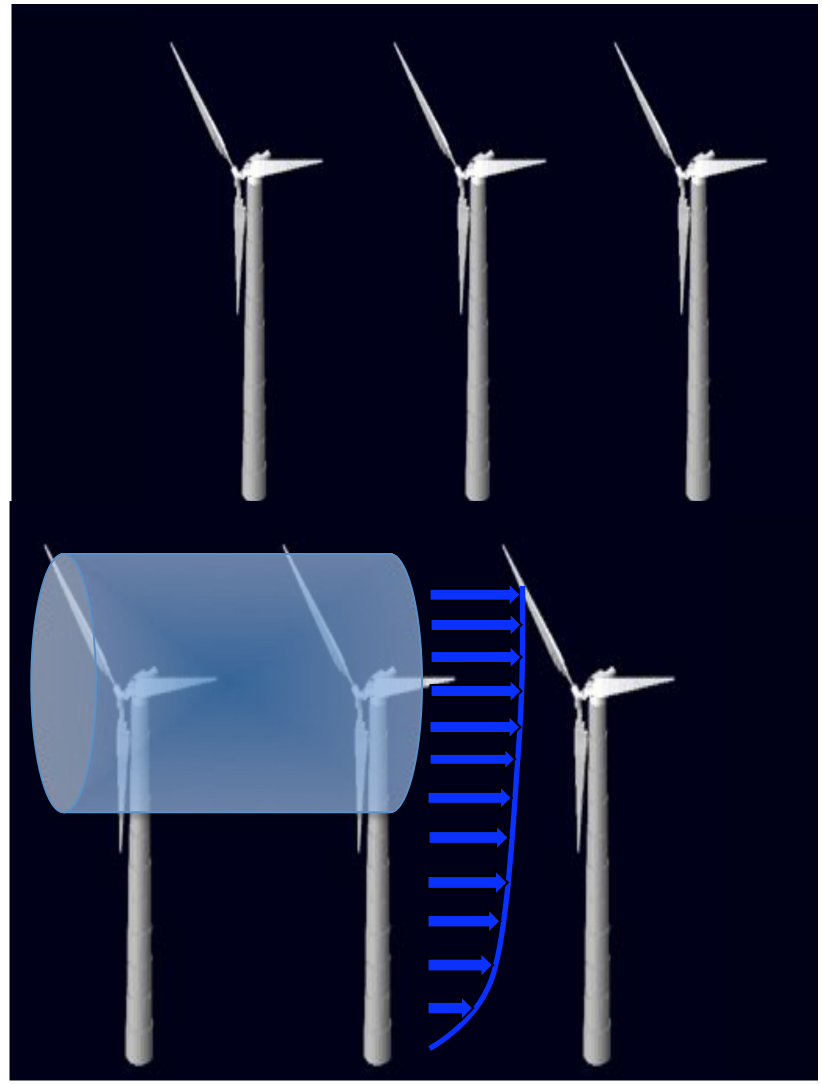
that can help engineers and owners optimize wind turbine and wind farm designs

Siting for noise, energy capture, and reliability

What is a Smart wind farm?

Can we identify & exploit interaction?

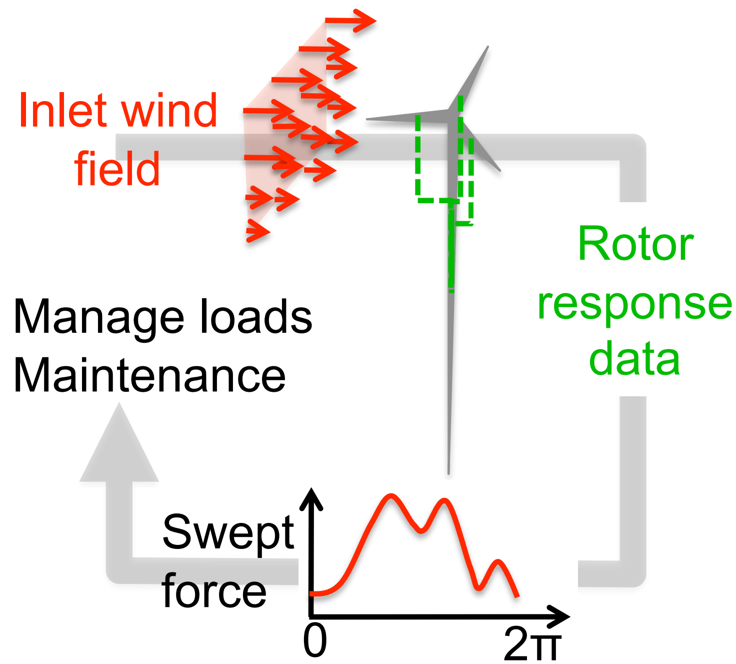
(If so, then we can optimize energy production at various sites and maximize uptime by reducing harmful loads.)



Characterizing Loads

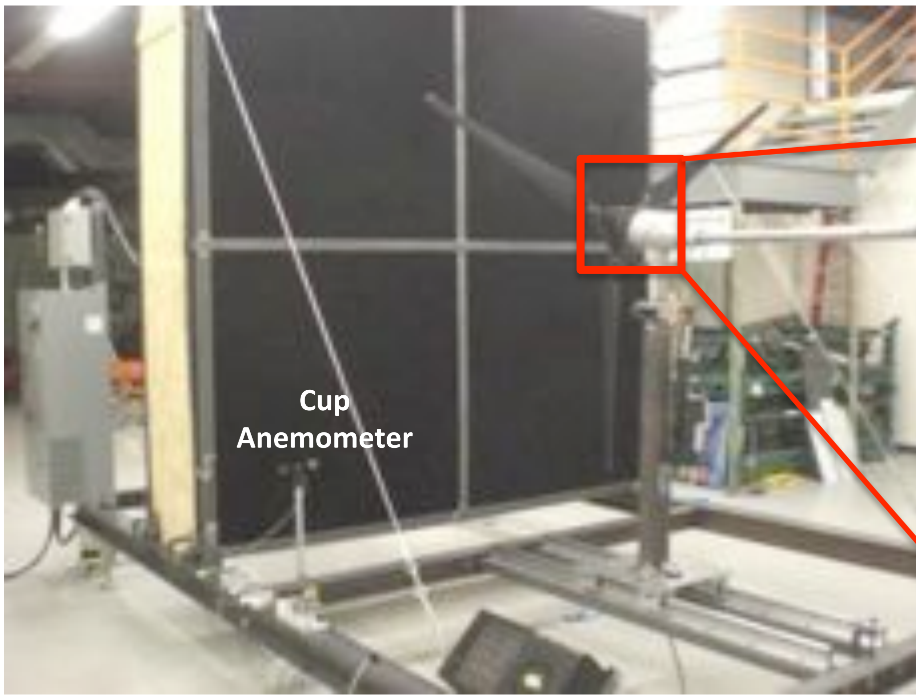
- Consider an offshore wind farm, where wake interactions are known to cause losses ~25%.

Milborrow, 2003, Wind Engineering and Industrial Applications
Barthelmie and Jensen, 2010, Wind Energy

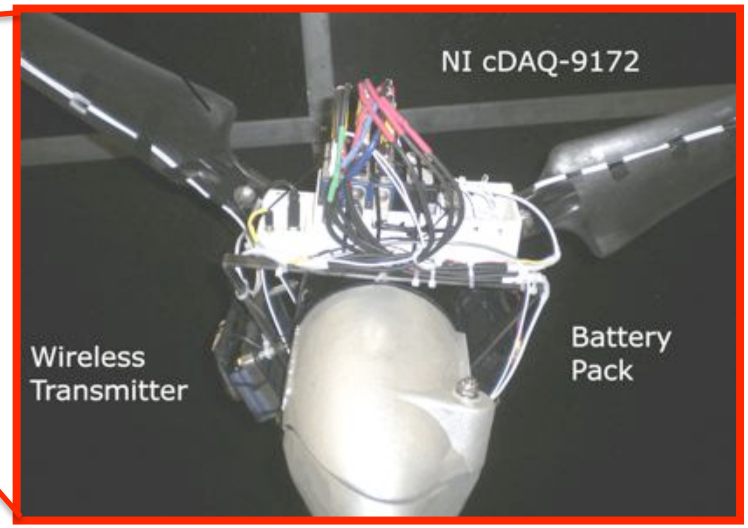


Wind Turbine Dynamics & Control Testbed

Wind Turbine Test Stand



Data acquisition hardware



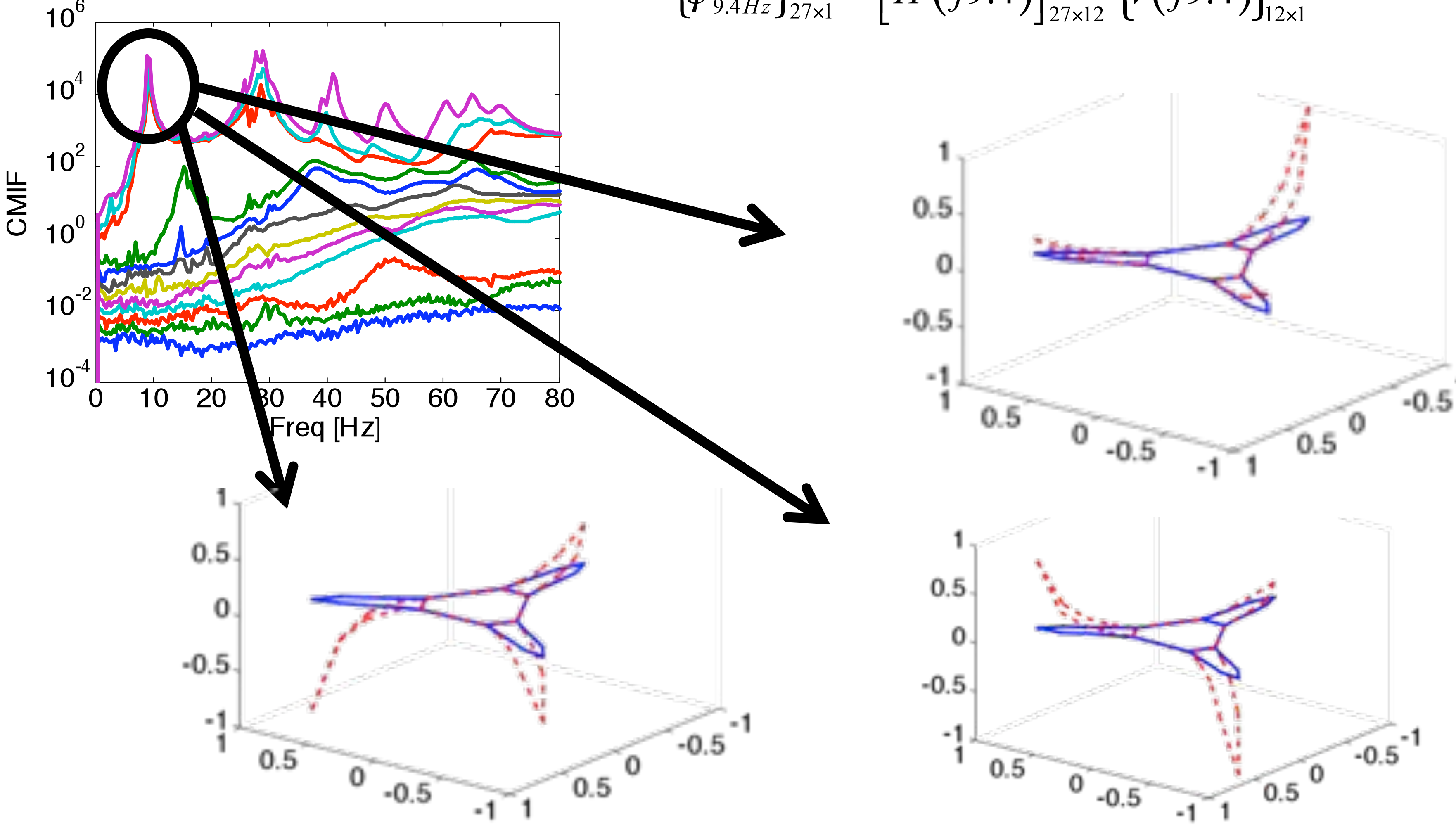
•Southwest Windpower® - Whisper 100™ (2.1m diameter)
•¼" honeycomb core
•4 – 48" diameter axial fans

•12V battery pack
•Gefen® Wireless USB 2.0 transmitter
•National Instruments® cDAQ

How Do Rotors Respond?

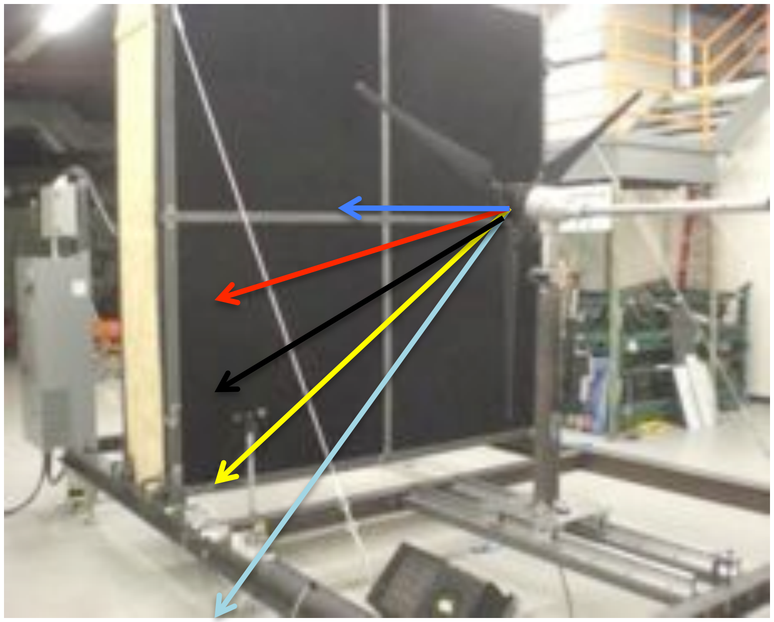
Complex Mode Indication Function

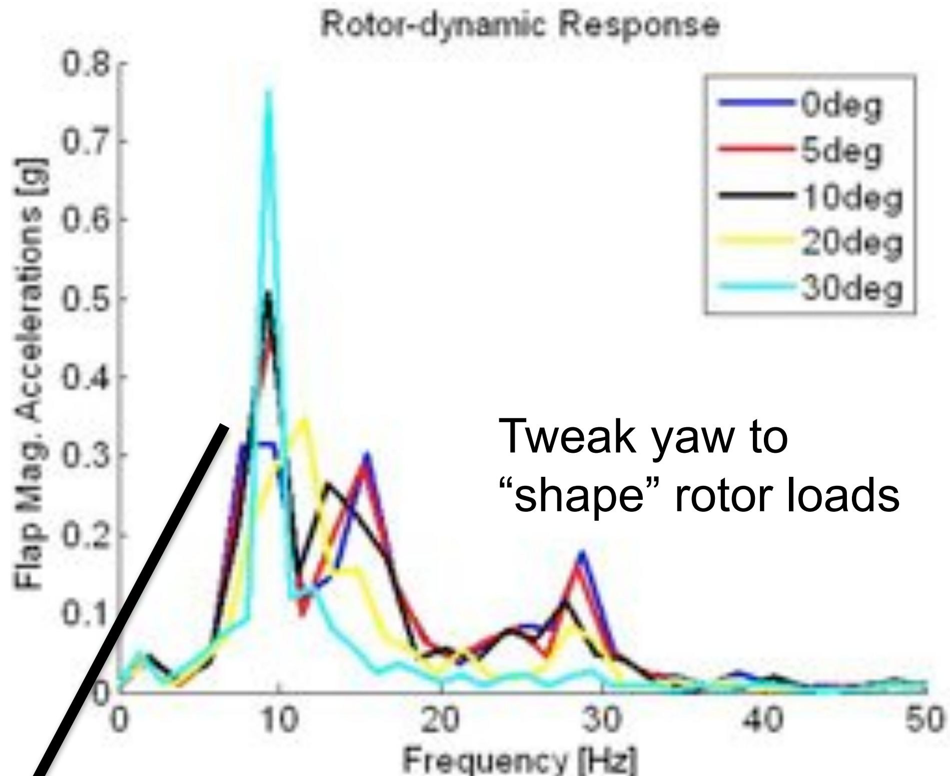
$$\left\{\psi_{9.4Hz}\right\}_{27\times1} = \left[H\left(j9.4\right)\right]_{27\times12}\left\{v\left(j9.4\right)\right\}_{12\times1}$$



Modal deflection shapes tell us about the distribution of loads on the rotor

Yaw Control for Loads





Tweak yaw to "shape" rotor loads

Yaw Angle (°)	Mean Voltage (V)	% Diff
0	3.068	-
5	3.0303	-1.23
10	2.9309	-4.47
20	2.5135	-18.07
30	1.8738	-38.92

1% change in power

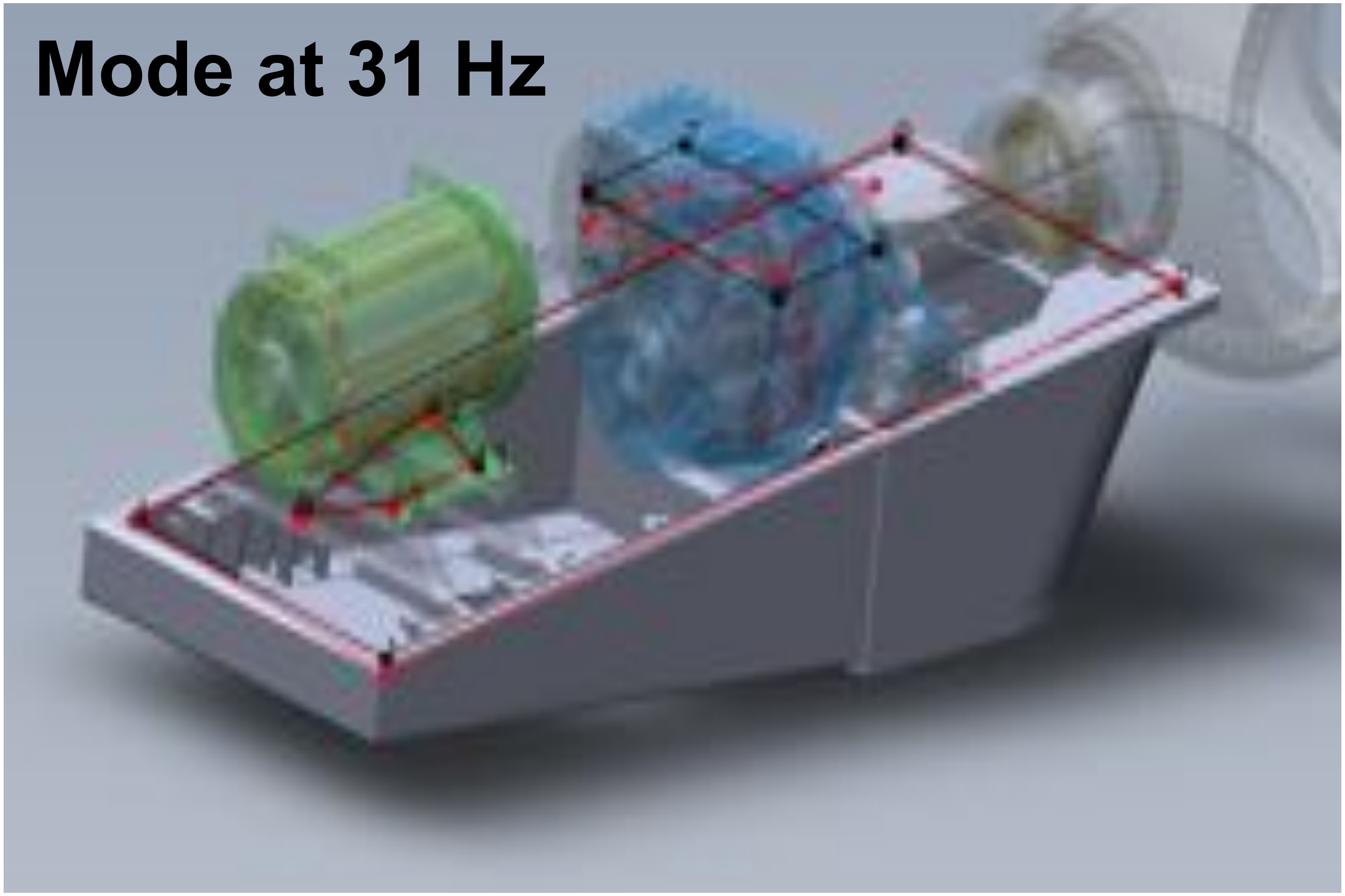
↓

40% change in blade response

What Does this Matter?

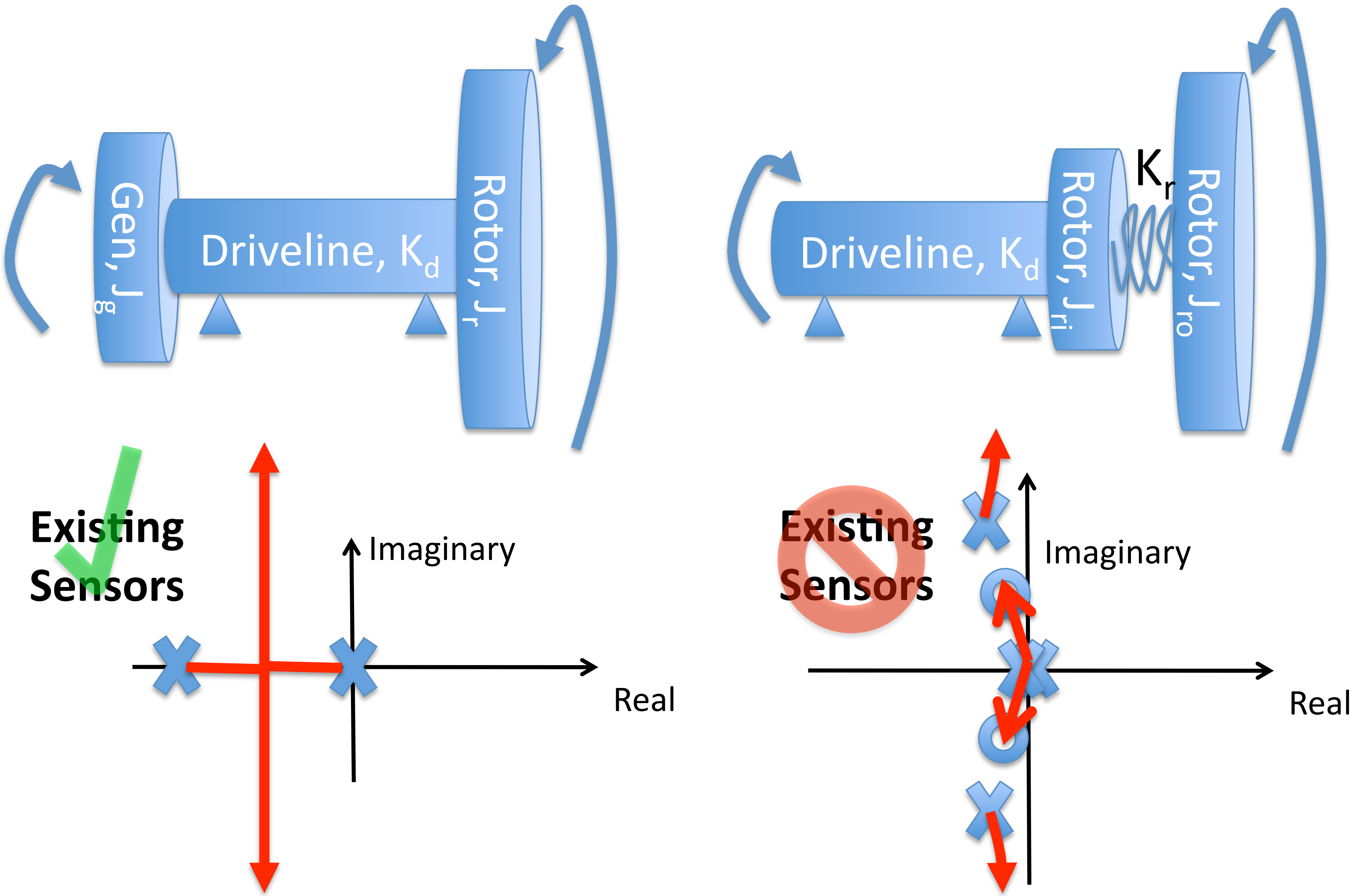
750 kW gearbox drive train tested at NREL Wind Technology Center

Modal Characteristics



Must avoid the coupling of the rotor response into the operation of the drive train

Why Blade Sensors?



Micro Reconfigurable Wind Farm

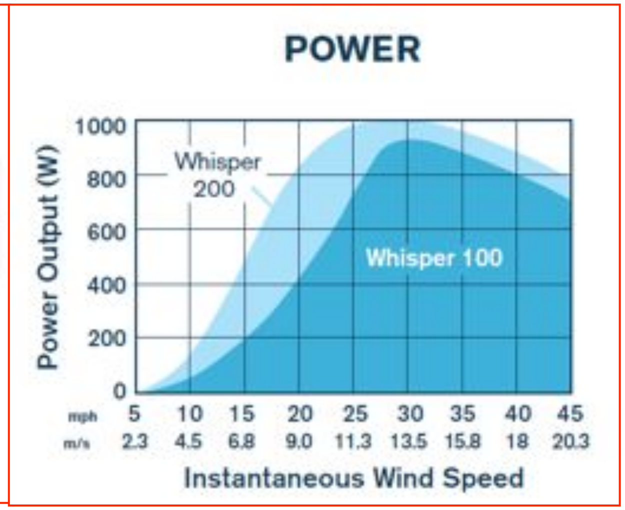
<u>Objectives:</u>

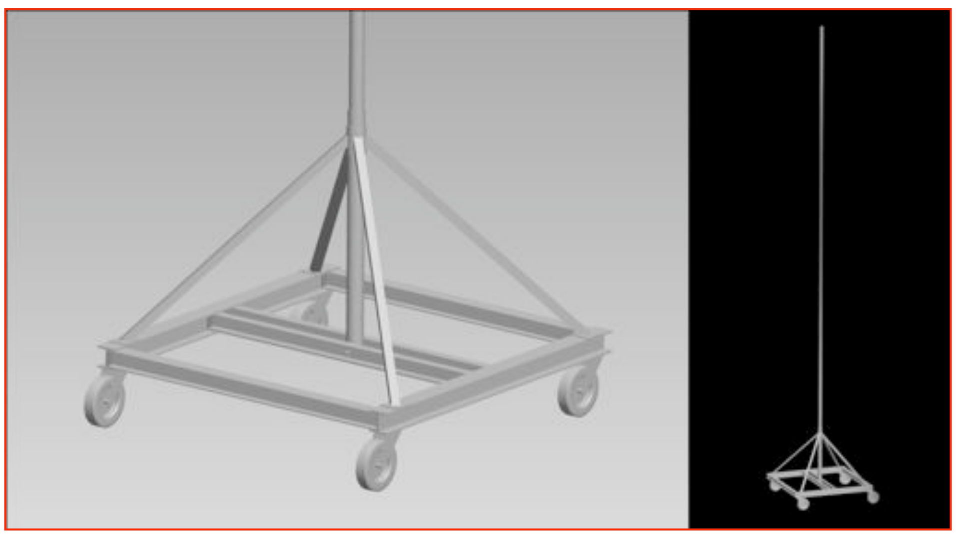
• Quantify aerodynamic interactions between turbines

• Investigate the effects of wind farm configuration on turbine performance & dynamic response

• Measure performance and dynamic response of each turbine to determine the influence of operating in wakes of upstream turbines

Wind Farm Specifications





<u>Wind Turbine Specs</u>

• Southwest Windpower Whisper 100 turbine

• 900 W Maximum Power at 28 mph

• 7 ft Rotor Diameter

<u>Mounting Cart Specs</u>

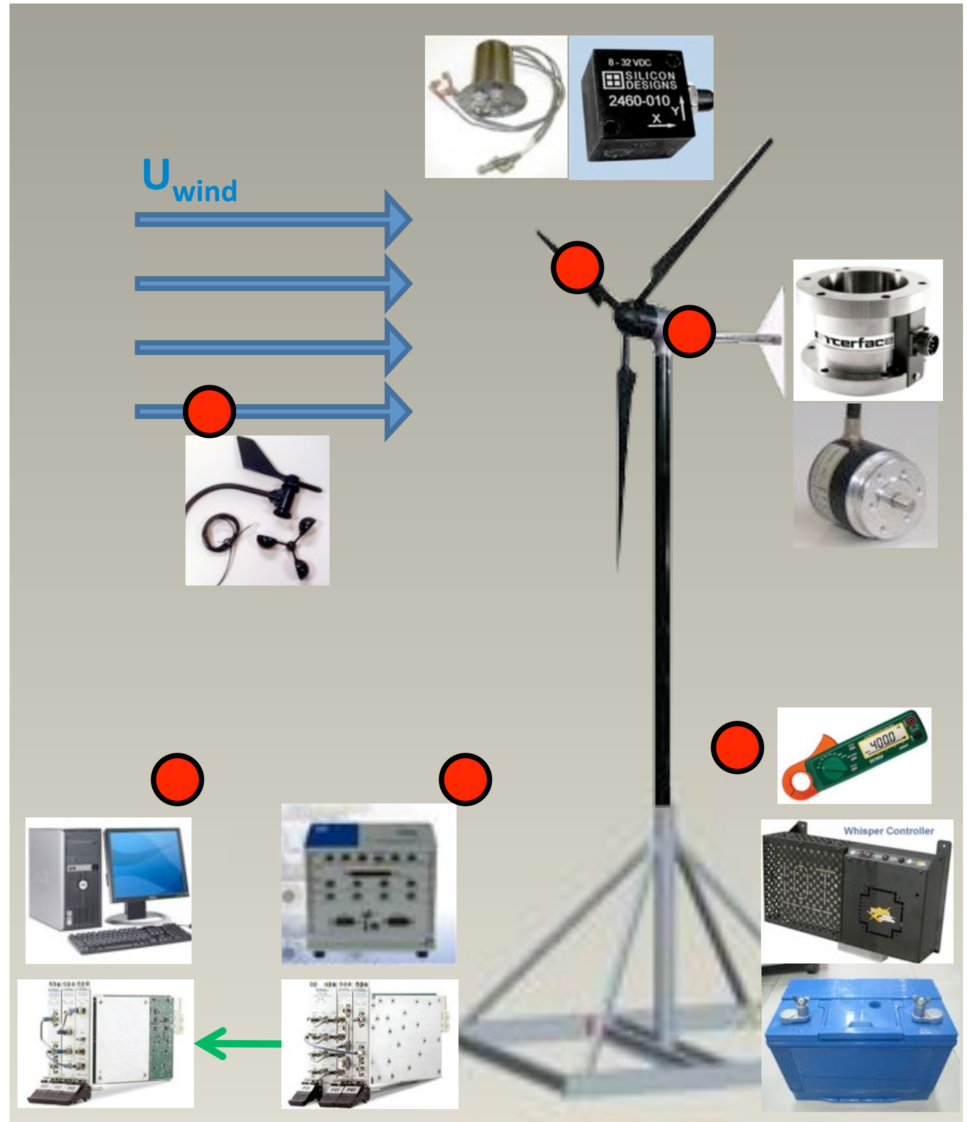
• 34 ft Turbine height

•7' x 8' platform - ~ 1100 lb

• Casters for repositioning & jacks for "permanent" operation

Wind Farm Instrumentation

- Wind Velocity and Turbulence quantified
- Blades Produce Lift and Excited Dynamically
- Rotor Torque Produced and Rotation Occurs
- Generator Produces Electrical Power which charges Batteries
- Data Acquisition collects Accelerometer, Torque Sensor, Encoder, and Electrical Power and transmits it wirelessly
- Data Received and Logged for Entire Farm



Wind Turbine Wake Modeling

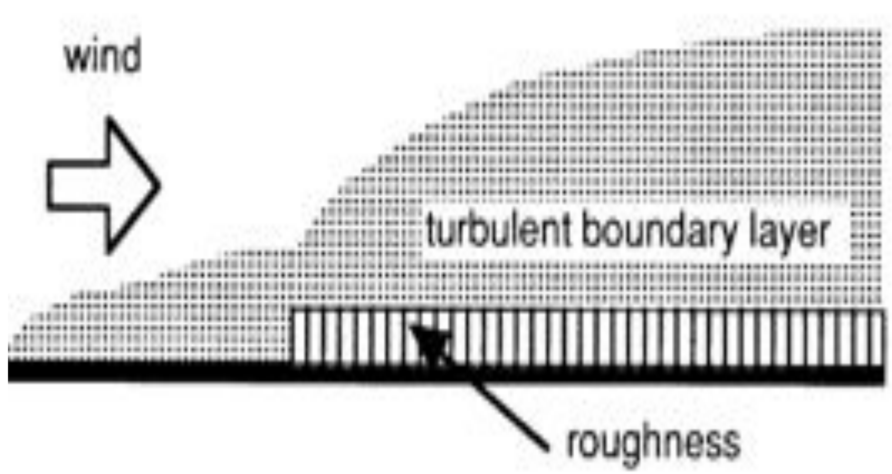
Objective: Improve the performance predictions for wind farms

- Model turbine wakes to improve power predictions
- Optimize wind farm layouts

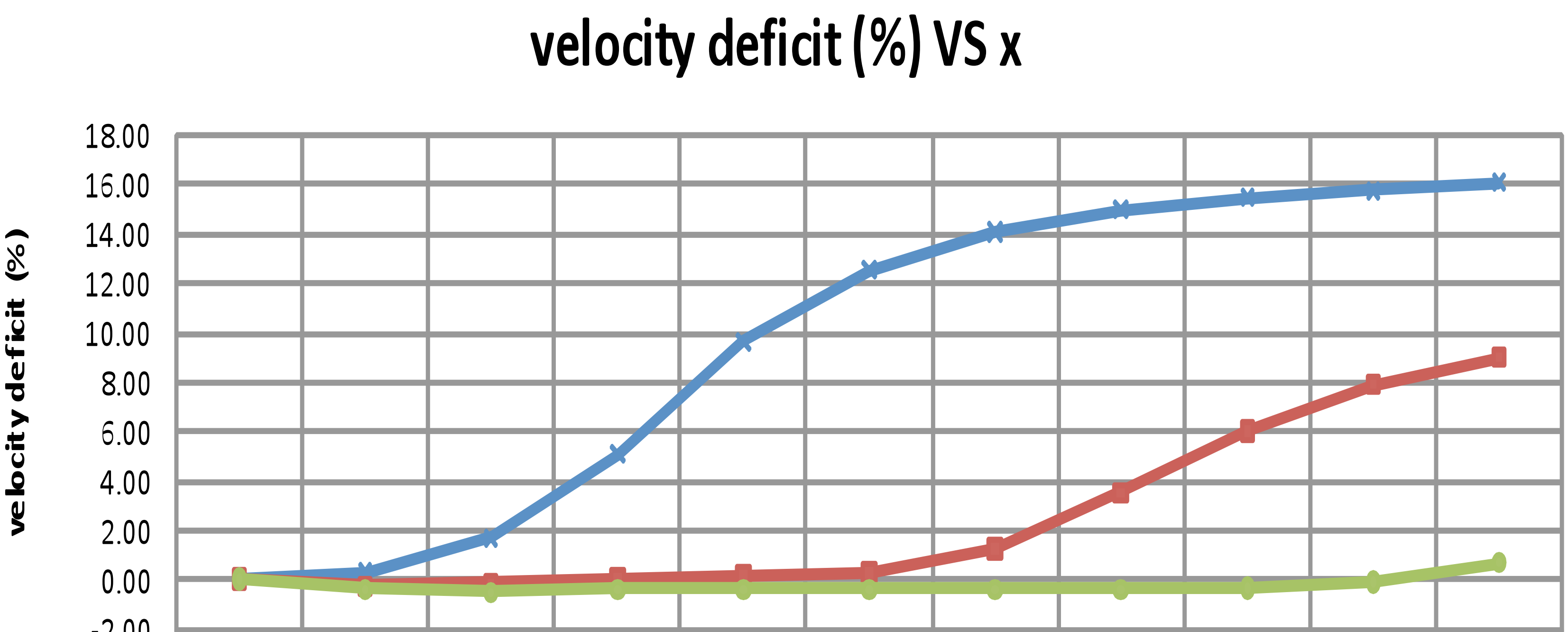
Approach: CFD modeling to provide detailed information

- Wind farm as a system
- Wind turbine & wakes

Wind Farm: Turbines modeled as surface roughness in atmospheric boundary layer



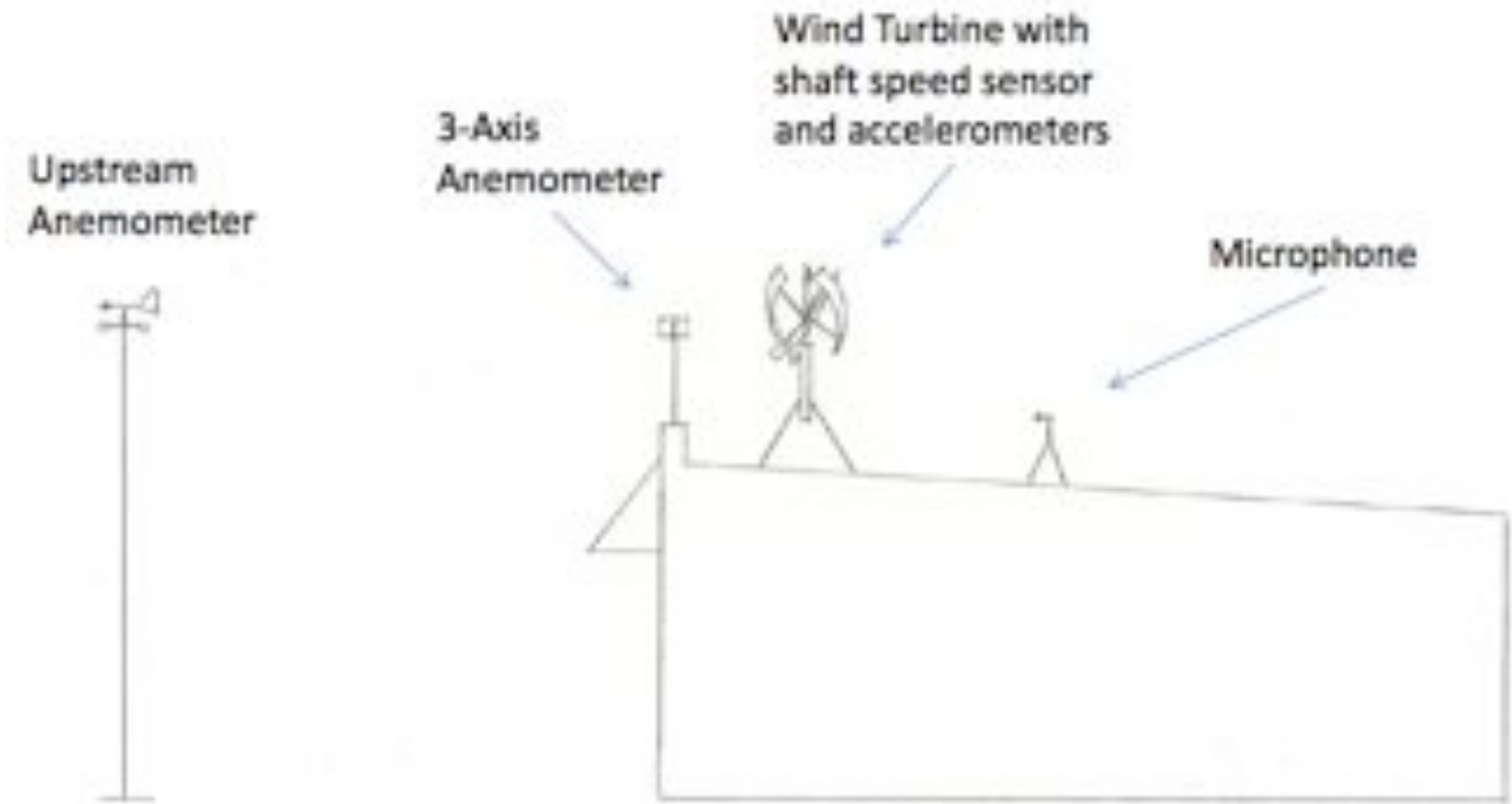
Wind Turbine Wake Modeling



	x=0m	500m	1000m	1500m	2000m	2500m	3000m	3500m	4000m	4500m	5000m
z=50m	0.00	0.30	1.67	5.05	9.59	12.48	14.00	14.92	15.37	15.68	15.98
z=100m	0.00	-0.27	-0.14	0.00	0.14	0.27	1.22	3.53	5.97	7.87	8.96
z=150m	0.00	-0.38	-0.51	-0.38	-0.38	-0.38	-0.38	-0.38	-0.33	-0.13	0.64

Urban Wind Farms

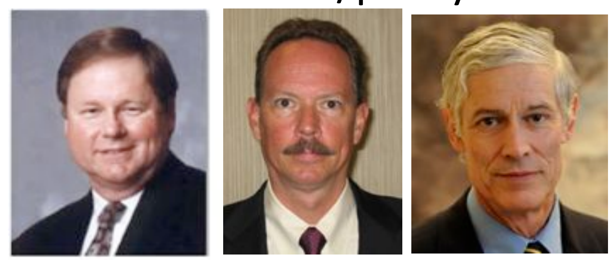
- Study VAWTs to better understand performance and noise in two typical urban environments.



Interdisciplinary

Rotors/fluid-structure

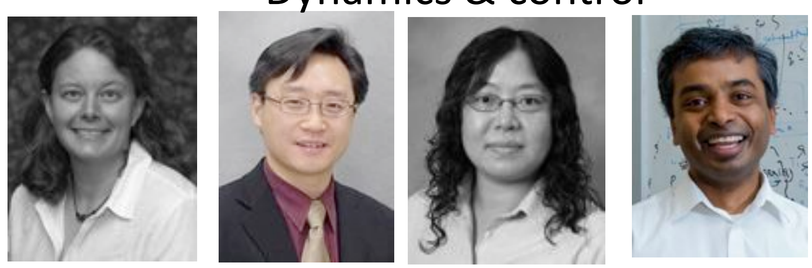
Economics/policy



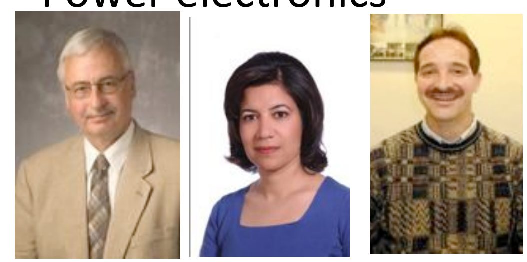
Reliability

Sensing

Dynamics & control



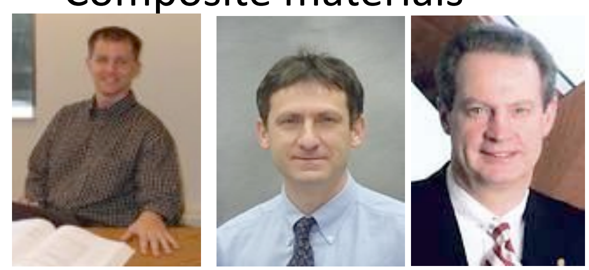
Power electronics



Noise

Climatology

Composite materials



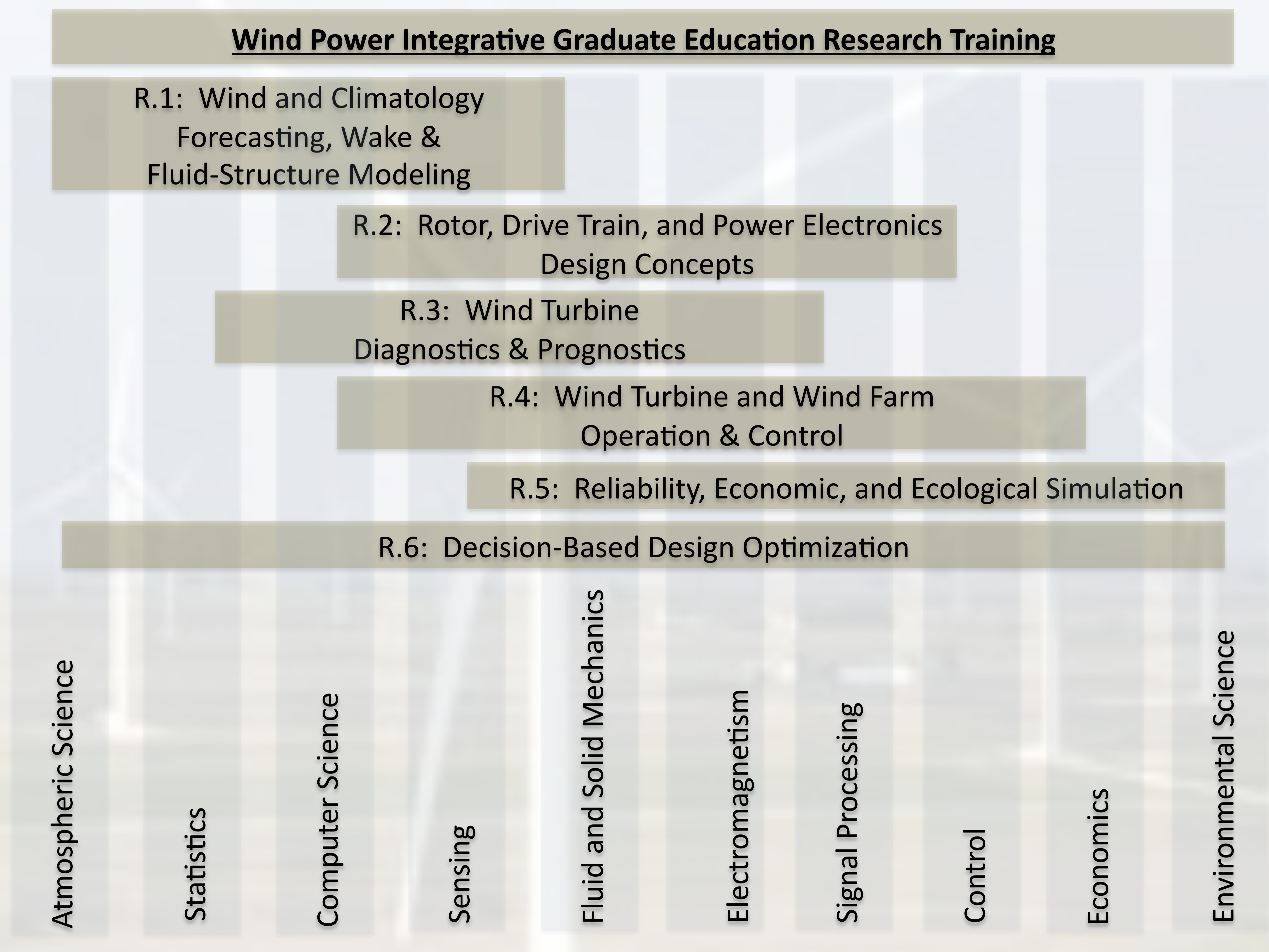
INDIANA UNIVERSITY BLOOMINGTON

UNIVERSITY OF NOTRE DAME

Sandia National Laboratories

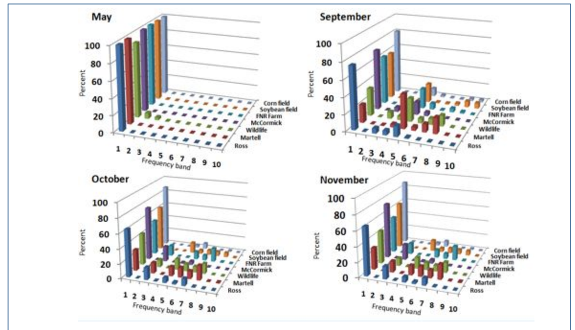
NREL NATIONAL RENEWABLE ENERGY LABORATORY

ESN ENERGY SYSTEMS NETWORK


Wind Power Integrative Graduate Education Research Training
R.1: Wind and Climatology Forecasting, Wake & Fluid-Structure Modeling
R.2: Rotor, Drive Train, and Power Electronics Design Concepts
R.3: Wind Turbine Diagnostics & Prognostics
R.4: Wind Turbine and Wind Farm Operation & Control
R.5: Reliability, Economic, and Ecological Simulation
R.6: Decision-Based Design Optimization
Atmospheric Science
Statistics
Computer Science
Sensing
Fluid and Solid Mechanics
Electromagnetism
Signal Processing
Control
Economics
Environmental Science

PURDUE UNIVERSITY Discovery Park Center for the Environment

Wind farm (1)



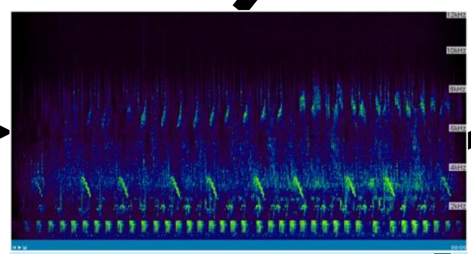
Frequency Band Dominance

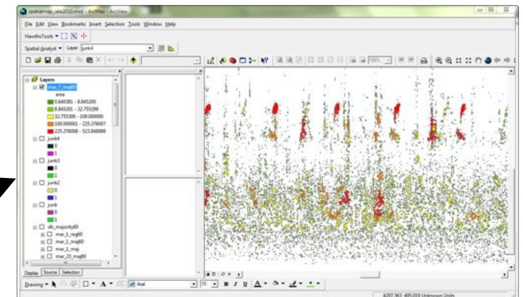
Bryan Pijanowski

Department of Forestry and Natural Resources

Purdue University

Row Crop (3)



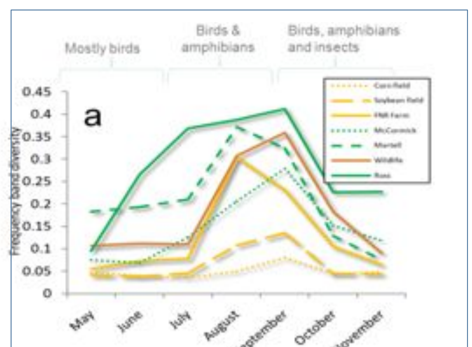


Amplitude Analysis

15 min recordings started top of every hour

24-bit wav file (12 Hz-10kHz)

Natural Forest (4)



Spectrogram Entropy

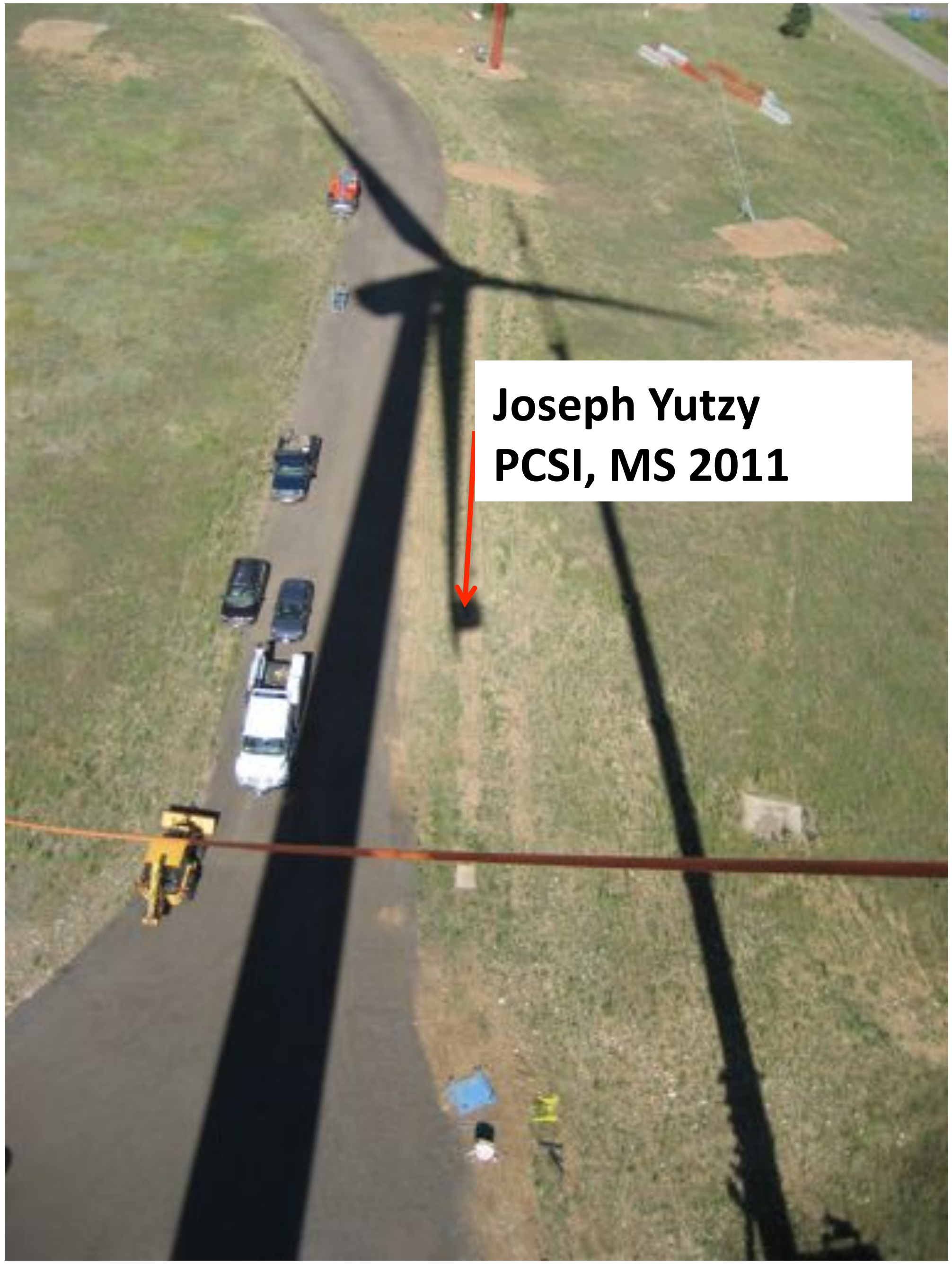
Land Value

- Wind Turbine Economics and Values
  - The Contract Defines the Landowner's Economic Value, i.e. Residual value to land
  - Income and tax stream
  - Decommissioning costs
- Other Critical "Values”
  - Nuisance - noise, NIMBY, visual
  - Environmental - habitat, wildlife
- These "Values" extremely difficult to determine, but are important.
  - Communities often make decisions on perception of these "Values"

A Step Change in Wind

The single most important thing we can do at the university to advance wind power is to train our students on relevant projects.

NREL, GE 1.6MW turbine



NREL, Gearbox Reliability Collaborative

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